PREPARED BY

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Model Input Status Report

H&H Modeling: Downstream Hydraulic Model

Pensacola Hydroelectric Project Project No. 1494

March 30, 2021

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Executive Summary

Mead & Hunt is assisting Grand River Dam Authority (GRDA) with its intent to relicense the Pensacola Hydroelectric Project (Project), which is regulated by the Federal Energy Regulatory Commission (FERC). Flood control operations at the Project are regulated by the United States Army Corps of Engineers (USACE). The FERC's study plan determination requires GRDA to provide a model input status report. This report documents the findings to be presented at the conference call related to the hydraulic model downstream of Pensacola Dam.

Mead & Hunt developed a one-dimensional (1D) HEC-RAS model extending from just downstream of Pensacola Dam and through Lake Hudson to just downstream of Robert S. Kerr Dam, where flood control operations are also regulated by USACE. The model geometry was developed from the best available topographic and bathymetric data, and bridge structures within the model were represented based on record drawings obtained from various agencies. The model was calibrated to four historic events based on measurements at the United States Geological Survey (USGS) stream gage near Langley, OK (USGS Gage No. 07190500) and observed water surface elevations (WSEL) at Kerr Dam.

List of Abbreviations and Terms

1D	One-Dimensional
CFS	Cubic Feet Per Second
CHM	Comprehensive Hydraulic Model
DEM	Digital Elevation Model
GRDA	Grand River Dam Authority
FERC	Federal Energy Regulatory Commission
NAVD88	North American Vertical Datum of 1988
NED	National Elevation Dataset
NGVD29	National Geodetic Vertical Datum of 1929
OWRB	Oklahoma Water Resources Board
PD	Pensacola Datum
PSP	Proposed Study Plan
RS	River Station
RSP	Revised Study Plan
SPD	Study Plan Determination
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSEL	Water Surface Elevation

1. Introduction and Background

1.1 Project Description

The Pensacola Hydroelectric Project is owned and operated by GRDA and regulated by the FERC. The Pensacola Dam is in Mayes County, Oklahoma on the Grand-Neosho River. Pensacola Dam impounds Grand Lake. Construction of Pensacola Dam was completed in 1940. **Figure 1** displays the study area. Downstream of Pensacola Dam, GRDA also owns and operates the Robert S. Kerr Dam as the Markham Ferry Hydroelectric Project. Kerr Dam is also in Mayes County and impounds Lake Hudson, also known as Markham Ferry Reservoir. Flood control operations at both Pensacola Dam and Kerr Dam are regulated by USACE.

1.2 Vertical Datums

Data sources for this study use a variety of vertical datums. Unless otherwise noted, data are presented in the Pensacola Datum (PD). To convert from PD to the National Geodetic Vertical Datum of 1929 (NGVD29), add 1.07 feet. To convert from NGVD29 to the North American Vertical Datum of 1988 (NAVD88), add 0.33 feet. **Figure 2** displays datum transformations and conversions (Hunter, Trevisan, Villa, & Smith, 2020). The HEC-RAS model discussed in this report was developed in NGVD29.

1.3 Study Plan Proposals and Determination

GRDA is currently relicensing the Project. The timeline of study plan proposals and determination is as follows:

1. On April 27, 2018, GRDA filed its Proposed Study Plan (PSP) to address hydrologic and hydraulic modeling in support of its intent to relicense the Project.
2. On September 24, 2018, GRDA filed its Revised Study Plan (RSP).
3. On November 8, 2018, the FERC issued its Study Plan Determination (SPD) for the Project.
4. On January 23, 2020, the FERC issued an Order on Request for Clarification and Rehearing, which clarified the timeline for certain milestones applicable to the relicensing study plan.

The PSP and RSP recommended the development of a Comprehensive Hydraulic Model (CHM). This report discusses the Downstream Hydraulic Model. The FERC's SPD and Order on Request for Clarification and Rehearing included the following direction:

1. Provide a model input status report by March 30, 2021.
2. Hold a conference call on model inputs and calibration within 30 days of the input status report.

This report provides the model input status and documents the development of the Downstream Hydraulic Model and findings to be presented in the conference call.

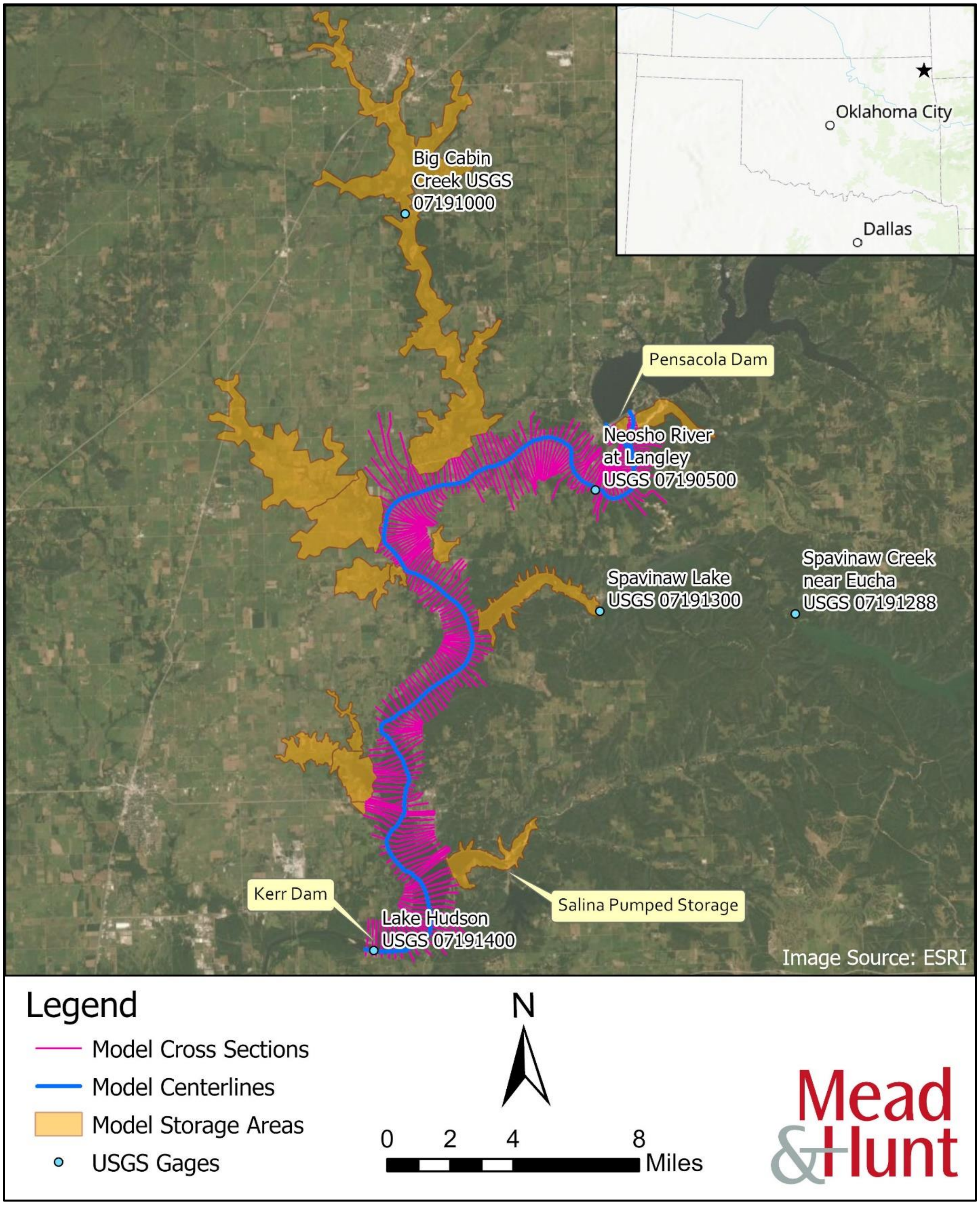
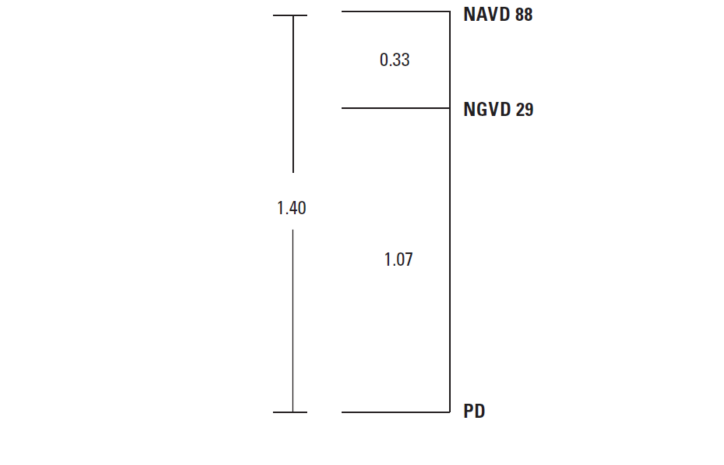


FIGURE 1. DOWNSTREAM HYDRAULIC MODEL STUDY AREA.



	Elevations, in feet		
	NAVD 88	NGVD 29	PD
Conservation pool	743.40	743.07	742.00
Top of the dam	758.40	758.07	757.00

FIGURE 2. DATUM TRANSFORMATIONS AND CONVERSIONS. SOURCE: (HUNTER, TREVISAN, VILLA, & SMITH, 2020)

2. Model Development

The Downstream Hydraulic Model was developed using HEC-RAS Version 5.0.7 and is a 1D, unsteady-state model. The various model components are discussed in the following sections.

2.1 Topographic and Bathymetric Data

Topographic and bathymetric data used to develop the Downstream Hydraulic Model consisted of a single Digital Elevation Model (DEM) to represent the bathymetry of the Neosho River, Lake Hudson, and overbank areas, as shown in **Figure 3**. The DEM was developed using the following data sources, listed in descending order of priority:

1. Oklahoma Water Resources Board (OWRB) bathymetry, representing the Neosho River and Lake Hudson from just downstream of Pensacola Dam to just upstream of Kerr Dam (Oklahoma Water Resources Board, 2008).
2. USGS National Elevation Dataset (NED) 1/3 arc-second elevation layer, representing the overbank areas (U.S. Geological Survey, 2017a).

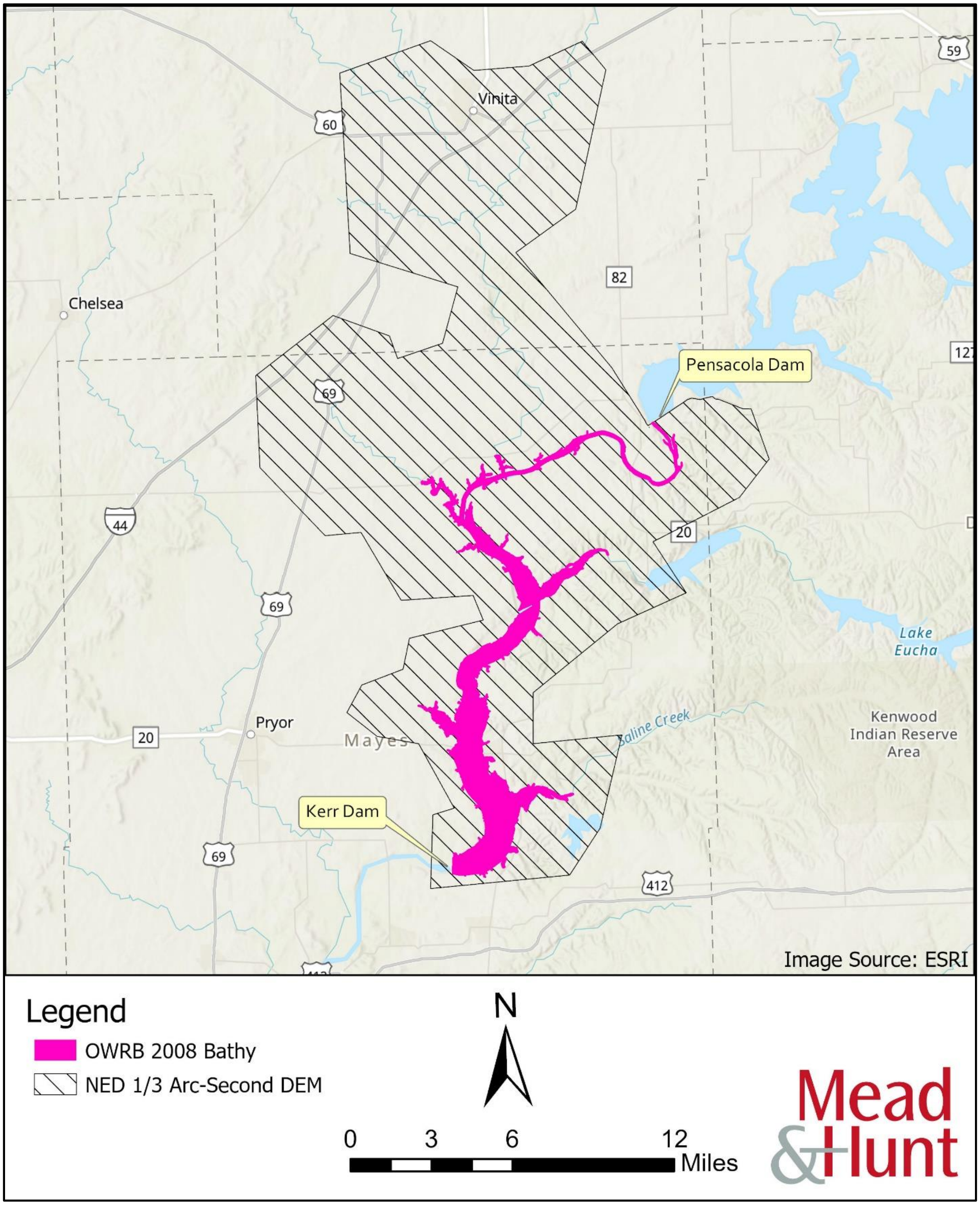


FIGURE 3. TOPOGRAPHIC AND BATHYMETRIC DATA EXTENTS.

2.2 Model Geometry

The model geometry was originally created using HEC-GeoRAS, a toolset used for processing geospatial data in ArcGIS for use in HEC-RAS. Cross-sections were defined for the Neosho River channel just downstream of Pensacola Dam to just downstream of Kerr Dam. Separate parallel reaches were defined for the Neosho River channel just below Pensacola Dam and the main spillway channel below Pensacola Dam, with these reaches joining each other approximately 1.6 miles downstream of Pensacola Dam. A single reach then represents the remainder of the Neosho River and Lake Hudson to just downstream of Kerr Dam.

Storage areas were developed in the model at various tributaries to the Neosho River and Lake Hudson to represent the available storage volumes outside the main flow path of the reservoir. A storage area was also used to represent the east spillway channel downstream of the Project from just downstream of Pensacola Dam, to where it joins the main spillway channel. An additional storage area was used to represent the potential flow exchange between the river channel and the main spillway channel below the Project. Lateral structures were used to connect the storage areas to their respective cross-sections.

Four bridges that cross the Neosho River and Lake Hudson within the study area were included in the Downstream Hydraulic Model. The bridges were defined within the model geometry based on record drawings obtained from the Oklahoma Department of Transportation and GRDA. Kerr Dam was represented by an inline structure near the downstream end of the model to assign a flow hydrograph boundary condition based on recorded discharges through the dam.

2.3 Manning's n-values

Manning's n-values for the Downstream Hydraulic Model were delineated based on land cover type, vegetation density, and development visible in aerial imagery. The n-values were established based on guidance provided in the HEC-RAS Hydraulic Reference Manual (U.S. Army Corps of Engineers, 2016). **Table 1** provides the land use categories and their respective n-values prior to calibration.

TABLE 1. MANNING'S N-VALUES PRIOR TO CALIBRATION.

Land Use Category	n-value
Channel	0.030
Pasture high grass or mature row crops	0.035
Mature field crops	0.040
Light brush and trees	0.060
Urban or residential	0.070
Dense urban or residential	0.090
Medium to dense brush	0.100

2.4 Unsteady Flow Data

The unsteady flow data for the model is comprised of multiple boundary condition types including inflow hydrographs, lateral inflow hydrographs, outflow hydrographs, and a normal depth boundary condition at the downstream end of the model. A uniform lateral inflow hydrograph boundary condition is also included in the model to represent ungaged tributaries along the reservoir and is discussed further in **Section 3**. Where available, observed times series data were obtained from USGS stream gages within the study area (U.S. Geological Survey, 2017b), (U.S. Geological Survey, 2017c), (U.S. Geological Survey, 2017d), (U.S. Geological Survey, 2017e) and used to develop the inflow boundary conditions and aid in model calibration. The applicable USGS stream gages are listed in **Table 2** and their locations are displayed in **Figure 1**.

TABLE 2. USGS STREAM GAGE STATIONS.

USGS Gage No.	Station Name
07190500	Neosho River near Langley, OK
07191000	Big Cabin Creek near Big Cabin, OK
07191288	Spavinaw Creek near Eucha, OK
07191300	Spavinaw Lake at Spavinaw, OK

Inflow hydrographs to the 1D model reaches were used to represent outflows from Pensacola Dam using time series data provided by GRDA. This data is summarized and sent to USACE monthly. Flows were split between powerhouse discharges and main spillway discharges accordingly.

Lateral inflow hydrographs were used to represent discharge from the east spillways at Pensacola Dam and flows from Big Cabin Creek, Lake Spavinaw, and Salina Pumped Storage Project. Discharges from the east spillways at Pensacola Dam were derived from USACE time series operations data. The gage locations for Big Cabin Creek and Lake Spavinaw are a considerable distance from the inflow locations represented in the model. Hydrologic routing parameters were obtained from the USACE Tulsa District's HEC-HMS model of the Lower Grand Neosho River Watershed and used to route the gaged flows to the lateral inflow locations within the HEC-RAS model. Flows from Lake Spavinaw were computed by using gaged outflows from upstream Lake Eucha, and back-calculating the outflow from Lake Spavinaw using routing parameters obtained from the USACE HEC-HMS model. Flows from the Salina Pumped Storage Project were derived from power consumption and generation time series data obtained from GRDA. This data was converted from megawatts to cubic feet per second (cfs) using separate conversion factors for pumping mode and generating mode, with positive flow rates representing inflows from power generation and negative flow rates representing withdrawals from pumping.

Outflows through Kerr Dam were represented with an outflow hydrograph assigned to the inline structure in the model using observed time series data obtained from GRDA and USACE. A normal depth boundary condition is assigned to the furthest downstream cross-section of the model. The model results for the study area upstream of Kerr Dam are not sensitive to the assumed normal depth slope because the flow hydrograph assigned at Kerr Dam allows the model to compute WSELs upstream of the dam independent of the computed water levels downstream of the dam.

3. Model Calibration

The Downstream Hydraulic Model was calibrated using four historic events which were chosen because they represent higher flow events for which suitable time series data were available with reasonable consistency. The four events used for calibration are summarized in **Table 3**.

TABLE 3. SUMMARY OF CALIBRATION EVENTS.

Event	Pensacola Dam Peak Outflow (cfs)	Kerr Dam Peak Outflow (cfs)
June 10, 2007 - July 23, 2007	106,941	99,034
April 7, 2008 - April 17, 2008	82,340	91,287
April 20, 2011 - May 15, 2011	80,559	91,852
May 17, 2015 - June 9, 2015	107,246	121,400

The HEC-RAS model was calibrated based on measurements at the USGS stream gage along the Neosho River near Langley (Site No. 07190500). The boundary conditions described in **Section 2.4** were used during calibration, with time series data specific to each event.

Initial model runs revealed discrepancies between the recorded data and actual data related to volume conservation errors, which caused modeled WSELs at Kerr Dam to vary significantly from the observed elevations through the course of the simulation. The most likely reason for the volume conservation errors is due to missing inflow from the ungaged tributaries and direct rainfall on Lake Hudson. The largest ungaged tributaries include Summerfield Creek, the lower portion of Big Cabin Creek, Rock Creek, Benge Branch, Wolf Creek, and Saline Creek. To correct for the volume conservation errors, a uniform lateral inflow hydrograph was used as an additional boundary condition in the model to distribute the missing inflow along the length of Lake Hudson. The lateral inflow hydrograph was computed for each event to minimize the difference between simulated and measured WSELs at Kerr Dam.

Manning's n-values were adjusted within the model in conjunction with the lateral inflow adjustments to provide a better match to the observed elevations at the Langley gage near the upstream end of the model. The goal of the Manning's n-value adjustment was to match the peak WSELs closely for all the calibration events using a single model geometry. The final calibrated model included an 8% increase in Manning's n-values from the initially selected values given in **Table 1**. Calibrated Manning's n-values are provided in **Table 4**.

TABLE 4. CALIBRATED MANNING'S N-VALUES.

Land Use Category	Calibrated n-value
Channel	0.0324
Pasture high grass or mature row crops	0.0378
Mature field crops	0.0432
Light brush and trees	0.0648
Urban or residential	0.0756
Dense urban or residential	0.0972
Medium to dense brush	0.1080

A summary of peak WSELs from the calibrated model and observed elevations at the Langley gage are provided in **Table 5**. The eight figures that follow show the computed stage hydrographs versus the observed stages for each of the four events at the Langley gage (**Figure 4**, **Figure 6**, **Figure 8**, and **Figure 10**) and at Kerr Dam (**Figure 5**, **Figure 7**, **Figure 9**, and **Figure 11**). The stage hydrographs show an acceptable match to the observed stages throughout each of the four events.

TABLE 5. CALIBRATION RESULTS AT LANGLEY GAGE.

Event	Observed Peak WSEL at Langley Gage (No. 07190500) (feet, PD)	Modeled Peak WSEL at Langley Gage (RS 73.315) (feet, PD)
June 2007	638.9	638.6
April 2008	636.9	636.9
April 2011	635.8	635.9
May 2015	639.5	639.6

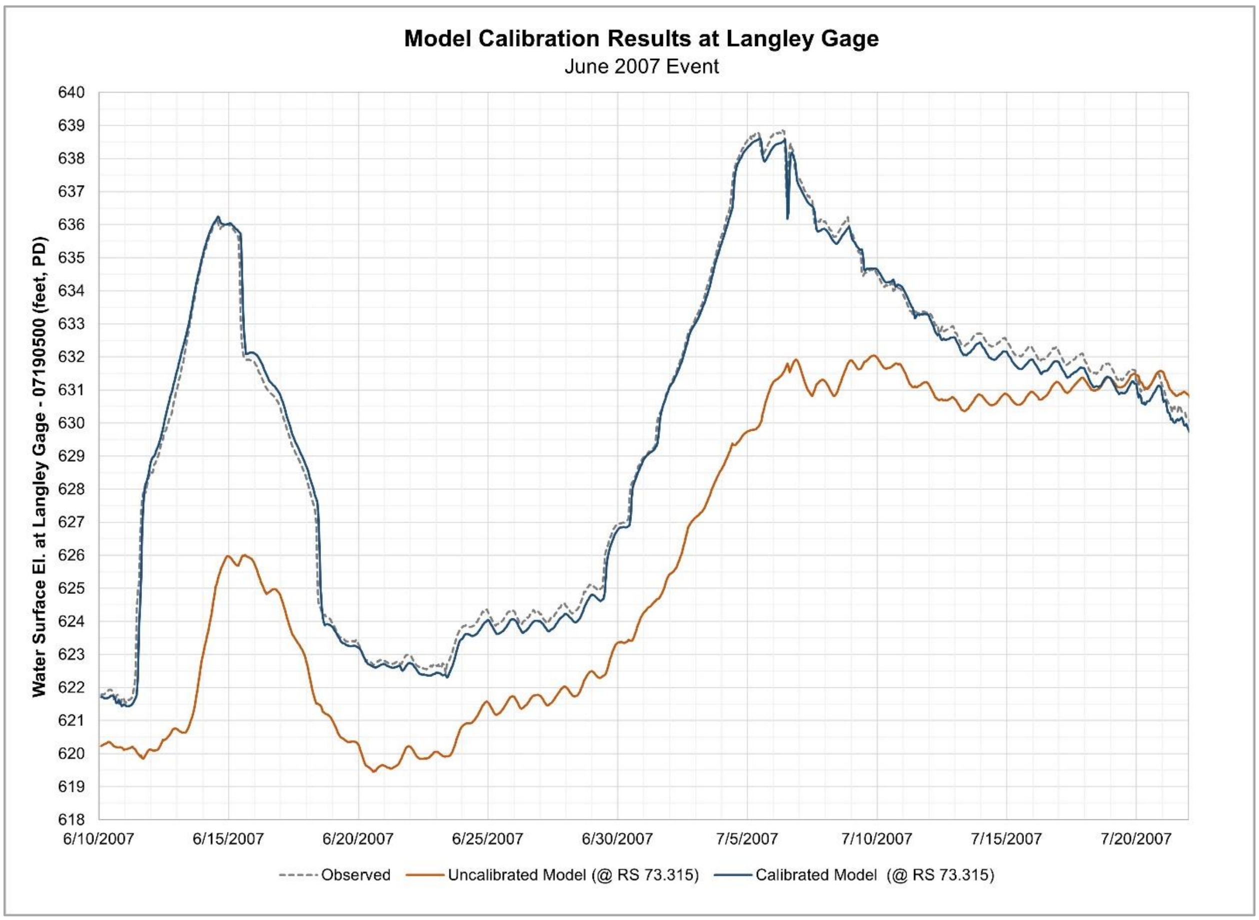


FIGURE 4. JUNE 2007 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

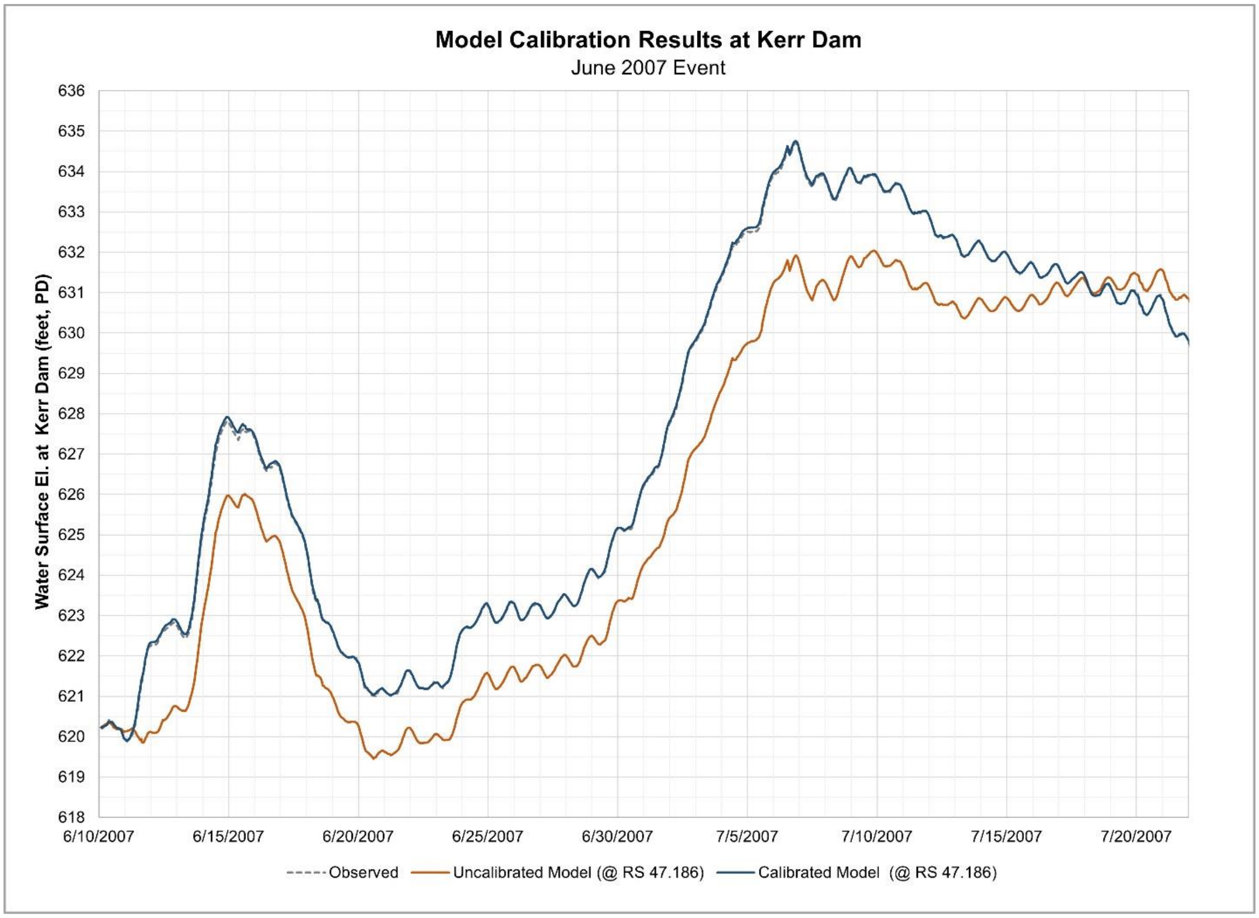


FIGURE 5. JUNE 2007 EVENT STAGE HYDORGRAPHS AT KERR DAM.

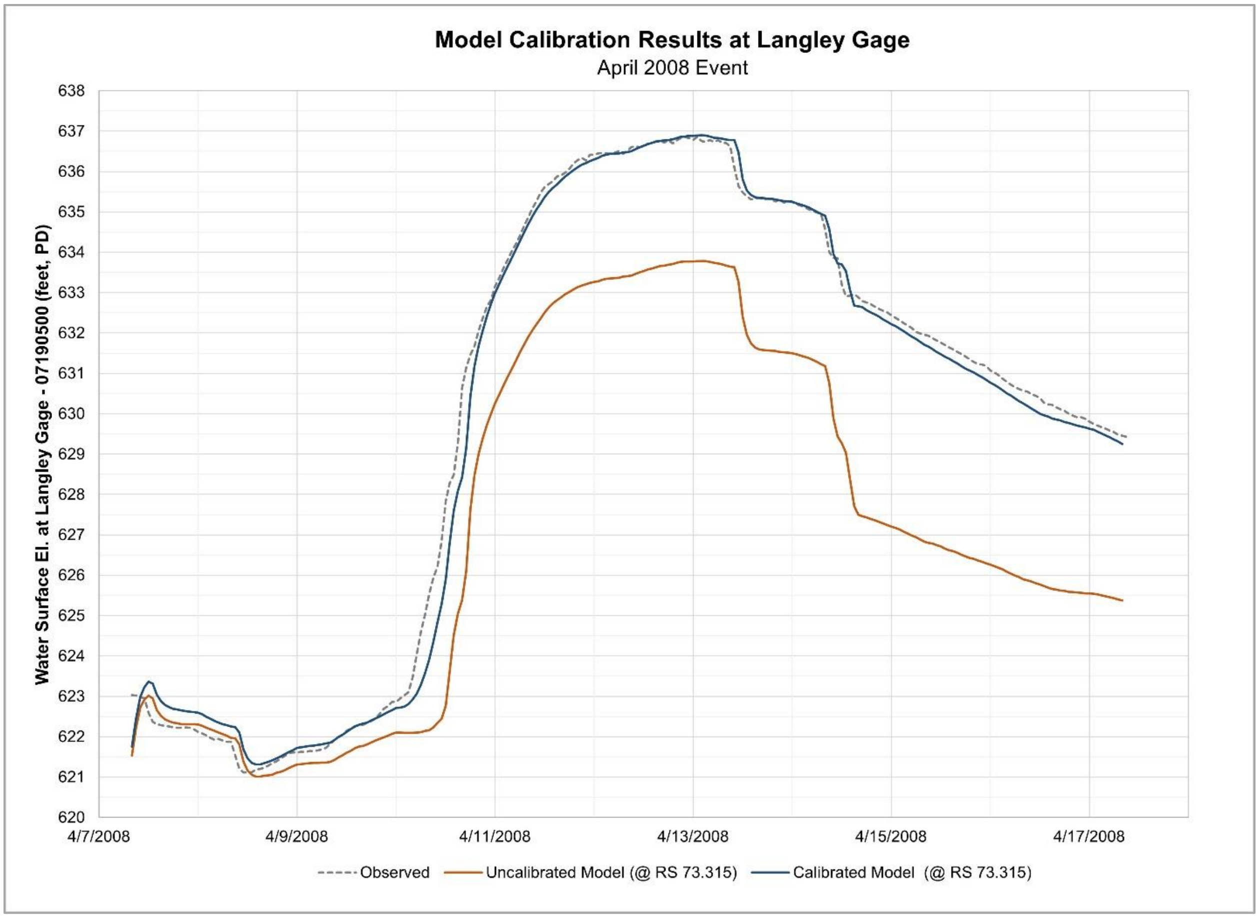


FIGURE 6. APRIL 2008 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

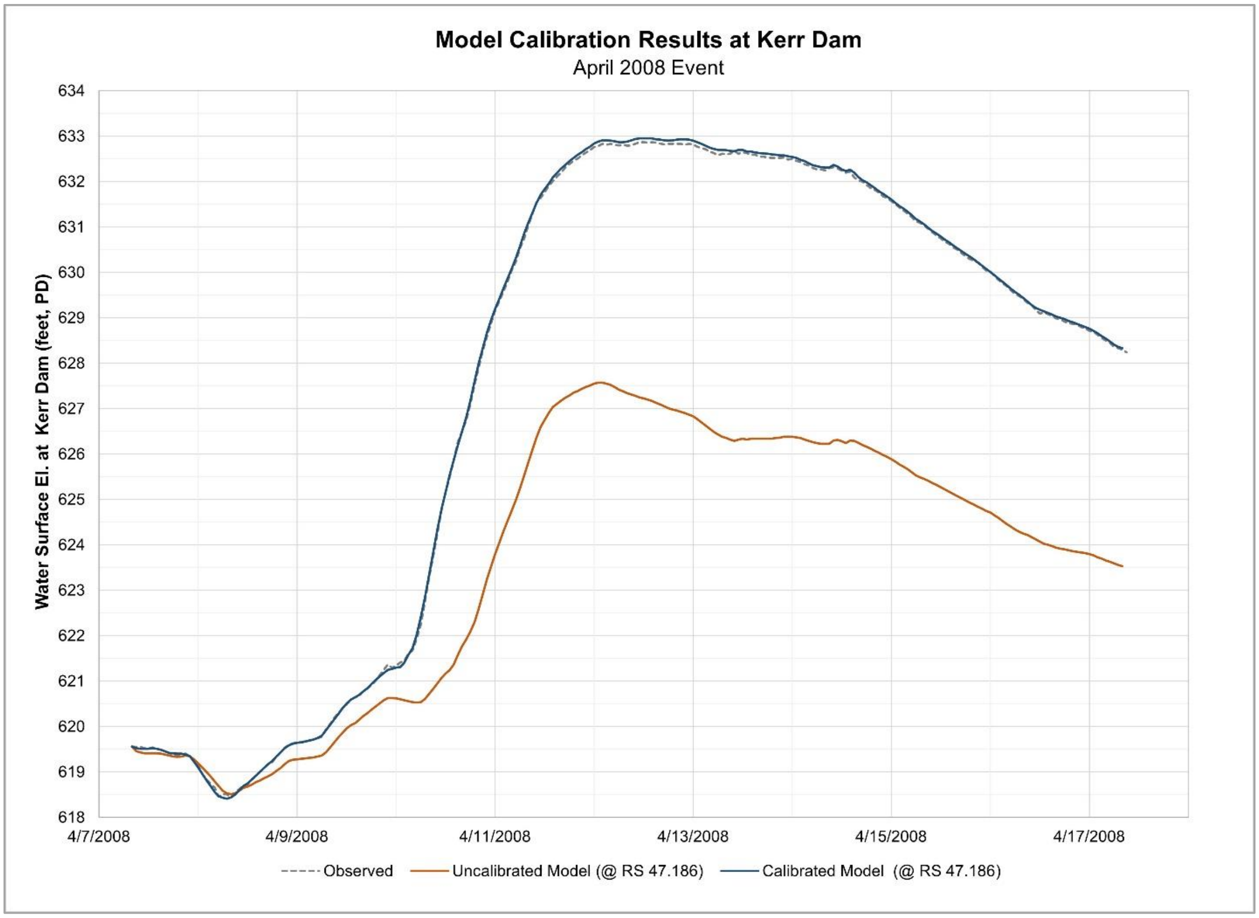


FIGURE 7. APRIL 2008 EVENT STAGE HYDROGRAPHS AT KERR DAM.

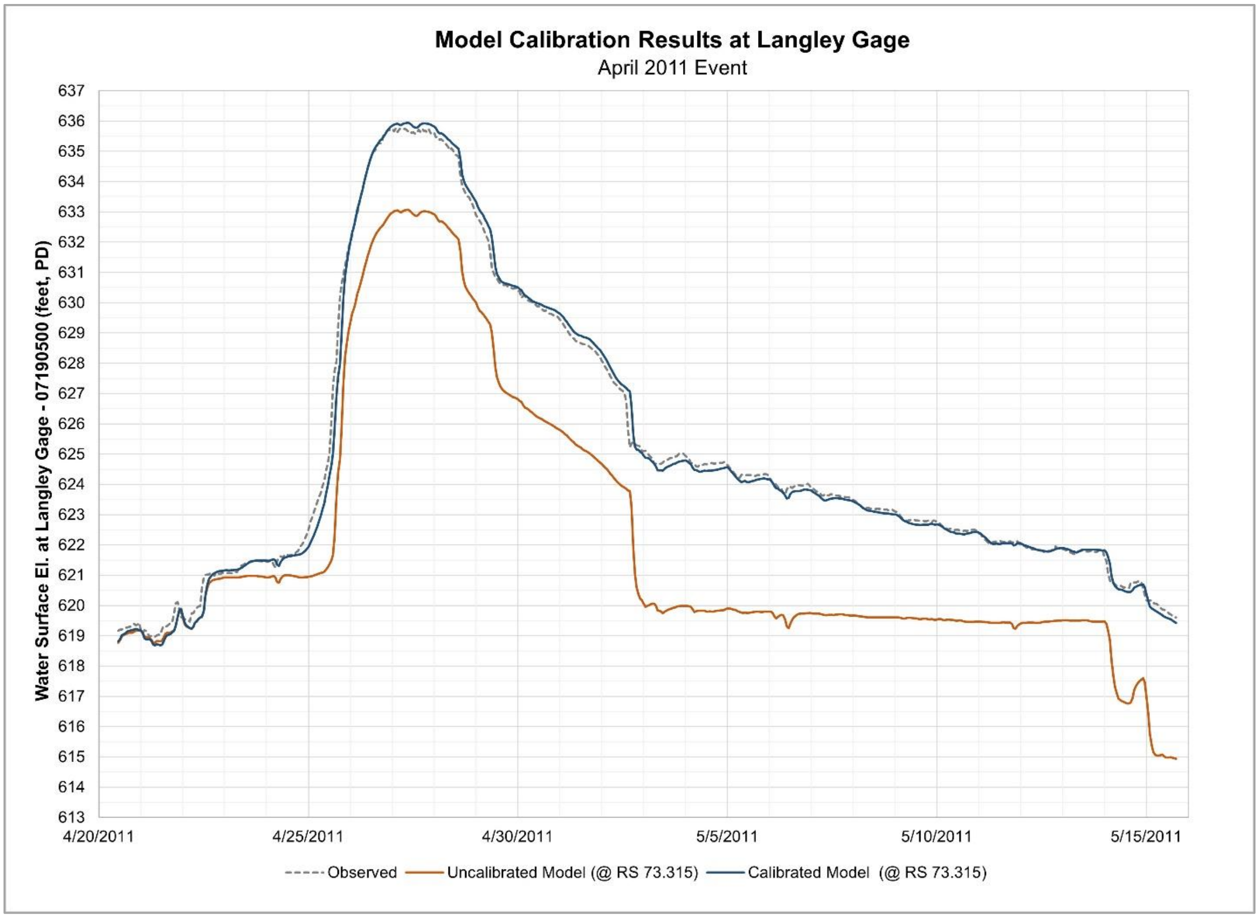


FIGURE 8. APRIL 2011 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

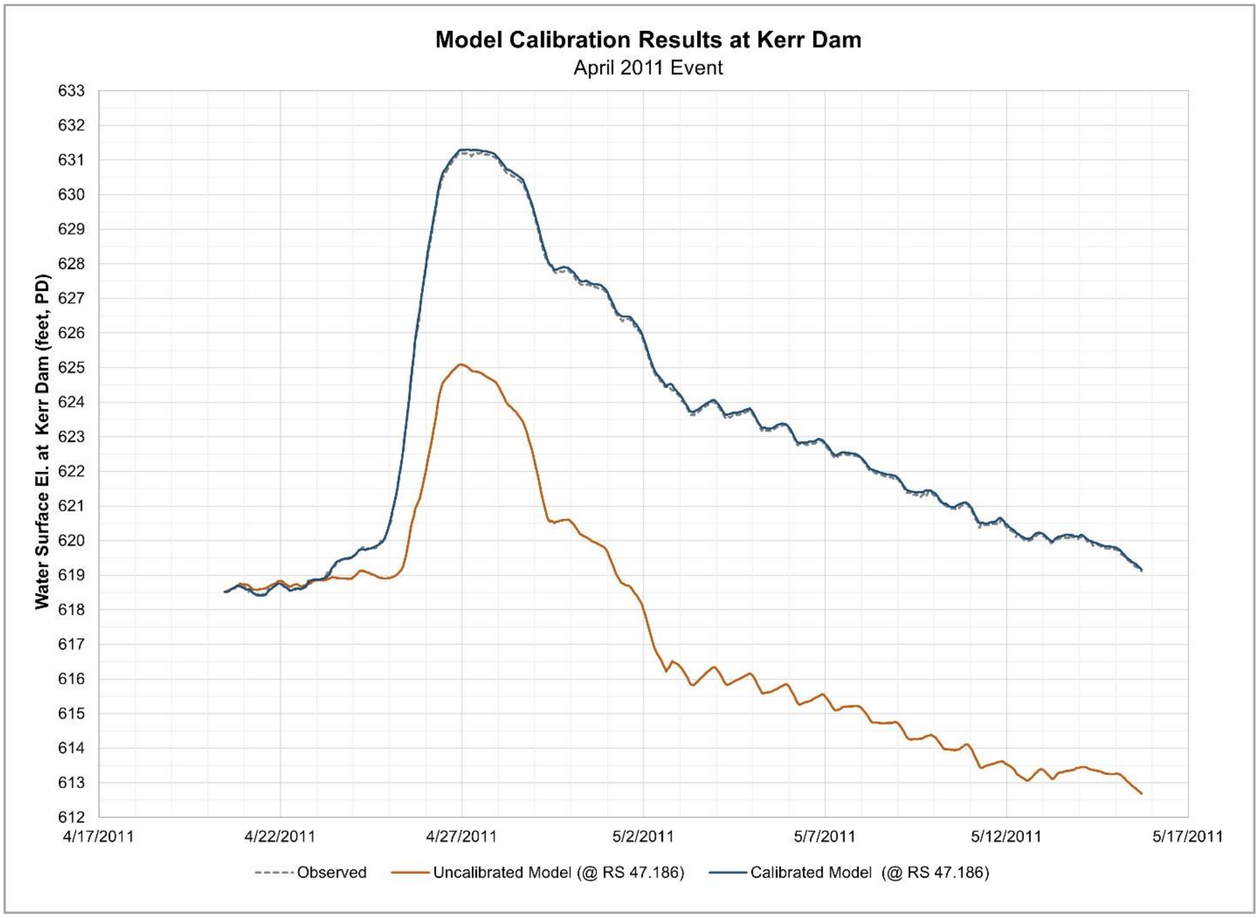


FIGURE 9. APRIL 2011 EVENT STAGE HYDROGRAPHS AT KERR DAM.

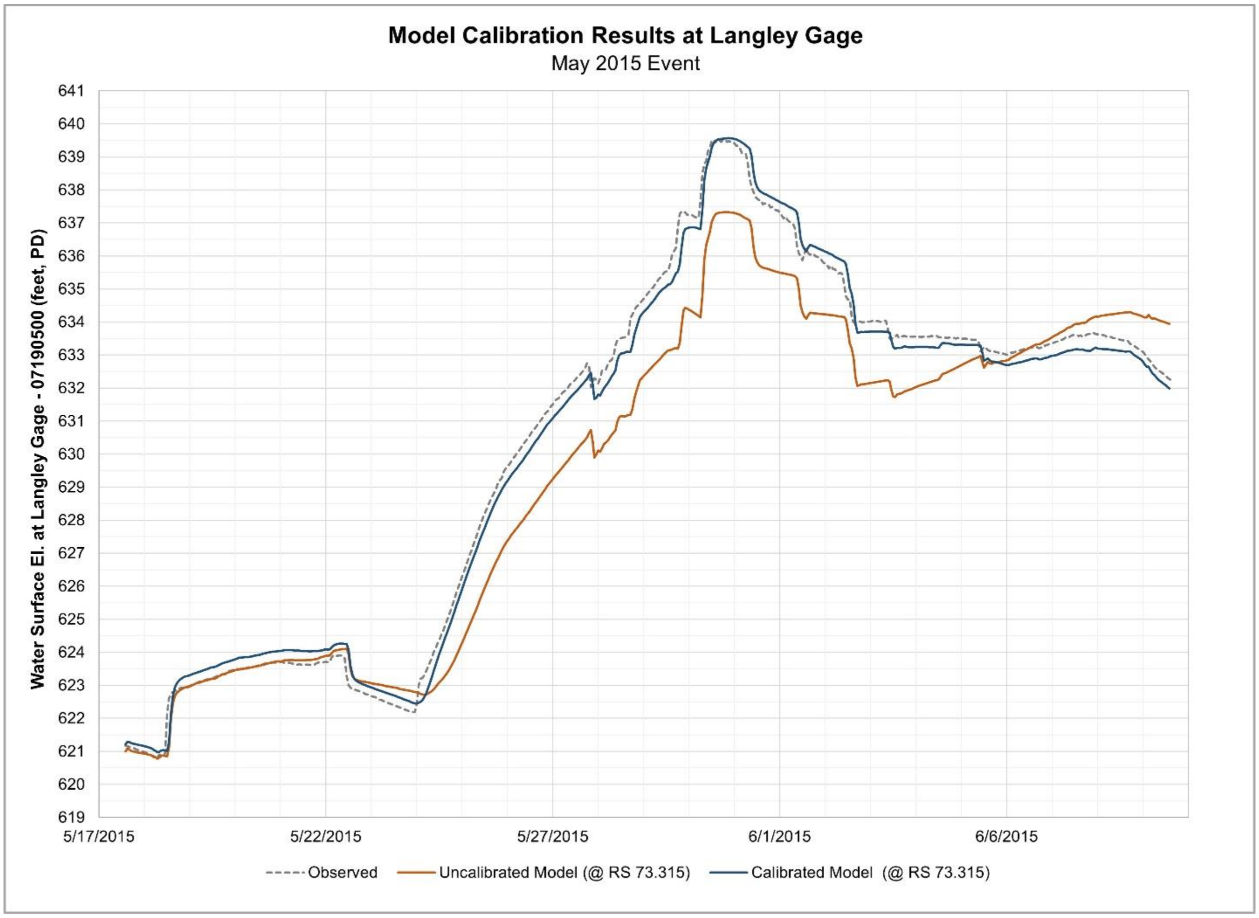


FIGURE 10. MAY 2015 EVENT STAGE HYDROGRAPHS AT LANGLEY GAGE.

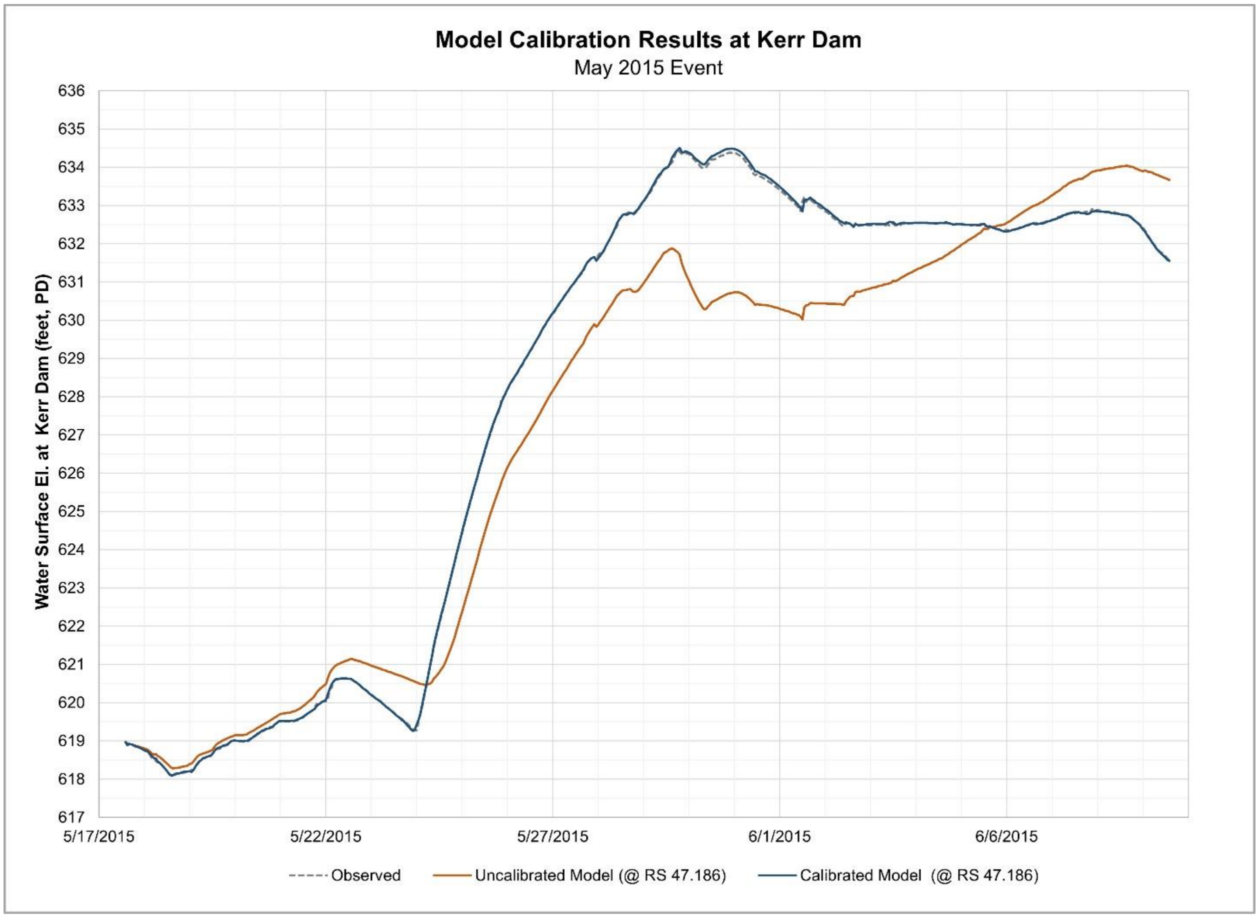


FIGURE 11. MAY 2015 EVENT STAGE HYDROGRAPHS AT KERR DAM.

4. Summary

GRDA is currently relicensing the Pensacola Hydroelectric Project and has enlisted Mead & Hunt to support the intent to relicense. Mead & Hunt developed a PSP and RSP that recommended the development of a hydraulic model downstream of Pensacola Dam. The FERC's SPD requires GRDA to provide a model input status report that includes the Downstream Hydraulic Model inputs and calibration. This report documents the development of the Downstream Hydraulic Model and findings that will be presented at the FERC-required conference call.

5. References

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